

GLASS-MAKING.

V.—GLASS IN SCIENCE.

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WHEN we compare the modern man, the product of many centuries of more or less continuous culture, with the men of ancient Rome, and still more with the men of ancient Greece, the impression unwillingly forces itself upon us that man has somewhat deteriorated since the days of Carthage and Thermopylæ. The reflection is a discouraging one. But observe how unavoidable it is. The modern man can not run so far or so fast, can not see so well, hear so acutely, or speak so loud. All his direct physical powers have suffered diminution. If the comparison be extended to the intellectual world, it is clearly manifest that the loss of power in one direction has not been compensated by the gain in another. One need have no great turn for Hellenism to perceive that the average American, despite his boasting, appears but a struggling child beside the heroes of either the Olympian games or the Athenian groves.

The effect of such a comparison as this is to make one question the truth of human evolution, and to ask himself in all seriousness whether the history of the race is not one of retrogression rather than of advance. But there is another way of looking at the matter, and there are other factors which must needs be taken into consideration.

The suggestion, I believe, is due to Mr. Spencer that, in attempting to measure man's physical power, the summary should not be limited to his direct faculties, but should justly include the acquisitions gained through the exercise of his intelligence. Thus, while it is perfectly true that modern legs are not so sturdy as Grecian legs, it must not be forgotten that by means of steamer and railway the modern man can girdle the earth in a couple of months, and can travel almost unlimited distances at the rate of fifty miles an hour. At the present moment popular lecturers are demonstrating that there is no reason why he should not go two and a half miles a minute. Since this facility of movement is the product of his own increasing development, we must admit that a longer view establishes an increased power of locomotion in the history of the race, and that even here evolution has been constant. The modern vision is faulty and astigmatic. We are veritable bats compared to the men of antiquity, or even to the modern American Indian. But here, again, the brain has more than compensated the defects of the eye. By means of the micro-

scope we see a world completely hidden from the more powerful eyesight of antiquity. By means of the telescope we study a multitude of distant worlds about which the Indian can not even speculate.

Stentor lived on the banks of the Bosphorus, not in a busy American seaport. The modern Stentor, with less perfect throat and lung and ear, speaks through telegraph and telephone across oceans and continents; and, in the phonograph, talks without regard to time or place.

One's first impression, then, of man's decrepitude must needs be modified. The evolution of power in matters purely physical is undeniable. In spite of this increase of power, however, the modern man is in many ways a poor creature and unlovable. It is an increase of power by deputy. With his narrow chest, dull ears, near-sighted eyes, and squeaky voice, even his multitudinous apparatus fails to make him comparable with the glorious creature who represented the best product of Greek culture. If our reflection ended here, even Mr. Spencer's very clever suggestion would scarcely make us thankful for an evolutionary process which had given us such doubtful progress. There has been an unquestionable falling off of personal power. The advance has been of the race. But we may believe without undue optimism that this failure of the individual will be but temporary. It is a period of acquisition. We may reasonably hope that this will be followed by a period of expenditure, when the gains of the race will be utilized. To-day, the majority busies itself with the means of living; to-morrow, it may find time to live. The faculties have been sacrificed to the demands of research and mental activity. When these have yielded their harvest, we may look for a wholesome reaction upon the faculties themselves. The knowledge which cost a human life, once gained, will serve a thousand lives. The philosopher whose bent form and bleared eyes bespeak research will be succeeded by a more beautiful generation who utilize his discoveries. Any smaller result would hardly justify the current martyrdom. The coming renaissance will be in the fine art of living.

In this evolution, the materials acted upon have ceased to be simply flesh and blood. The human activity is largely cerebral, while its materials are inanimate. To supply them the three kingdoms of Nature have been ransacked. It is the purpose of the present paper to indicate in a measure the contributions which glass has made to this evolutionary process, for its office is one of increasing importance. In the search for power, the qualities which have given glass so large a value are those particularly of refraction and transparency. These qualities, combined with its hardness and indifference to most chemical

reagents, make it one of the most useful of servants in the good cause of science.

First, then, a word in regard to its refractive power.

If a beam of light pass from one medium to another of different density, such as from air to water, its course is not altered, provided the surfaces of the two media be at right angles to the beam. A penny placed in a basin of water looks in no way distorted if the eye be directly above the coin. But when a beam of light passes into a second medium at other than a right angle its course is bent. A straight stick, partly immersed in water, looks crooked because the light reflected from the portion beneath the water is bent on entering the air. The fact is familiar to every one. This bending of the light has received the name of refraction, and its laws are exceedingly simple. If the beam pass into a denser medium, as from air into water, the bending is *toward* the perpendicular to the common surface of the two media. On the other hand, if the passage be into a rarer medium, as from water into air, the beam is bent *away* from the common perpendicular. We may, then, predict in a general way the course of a beam of light when it changes its medium, but in scientific work we must do better than that—we must know the exact course of the beam. This brings us to the second law of refraction, which is quite as simple as the first, but which requires, if one is not mathematically inclined, a trifle more patience for its comprehension. In any angle, if a perpendicular be dropped from any point on one side to the opposite side, the ratio between the perpendicular and the distance of its starting-point from the apex of the angle will evidently be a constant quantity for that angle, wherever the point be taken. This ratio is called the sine of the angle. If one will take the trouble to draw a series of angles from zero to ninety degrees, he will readily see that the value of the sine increases from zero to unity, and that these are its limits.

Now, it is found by experiment that the ratio between the sine of the angle of incidence (the angle which the impinging ray makes with the common perpendicular to the two media) and the sine of the angle of refraction (the angle which the refracted ray makes with the common perpendicular) is a constant quantity. This quantity is known as the index of refraction.

But it may be asked what all this has to do with glass-making. Essayists are prone to talk about evolution and the fourth dimension of space, and many other things which seemingly have no connection with the subject in hand. In this case, however, the wandering is justifiable, for the index of refraction is a constant which must ever be borne in mind by the scientific glass-worker, if he wishes to use the material in the construction of optical in-

struments. In general, the greater the index of refraction, the more available the glass. The practical question with him is to know the conditions which affect the index of refraction. To answer this intelligently, one must consider why the light is bent at all in changing its medium. If a bather run down a smooth, hard beach into the water, he is very apt to fall head foremost when he reaches the denser medium. His feet are suddenly retarded, while his body keeps on through the air with the old velocity. The result is a change of direction in his motion, which is in one sense disastrous.

Precisely the same thing happens to the light. It is generally conceded to be a progressive wave-motion. When the beam passes into a denser medium at an angle, the side of the beam which enters first is retarded, while the other side keeps on at the old velocity. The result is, that the whole beam is swung out of line and takes a new direction in the new medium. The index of refraction is simply a quantitative expression for this bending, and depends upon the nature of the substance and its density. The great brilliancy of the diamond is due to its very high refractive index, and the sparkle of cut glass is the result of a similar property.

Since the employment of glass in optics depends upon its ability to bend the rays of light to a common point or focus, its value increases with its refractive power—that is to say, with its density. The problem set before the maker of optical glass is, therefore, quite different from that which must be solved by the manufacturer of more every-day goods. He must produce a glass which has great weight without any loss of transparency. The difficulty lies in this, that the substances which add weight to the glass are prejudicial to its transparency. Success is found in the nice balance between these opposing tendencies.

Glass is a double silicate. If it is to have large density, the metallic bases combined with the silica must be heavy. Hence, the ordinary glass of commerce—a double silicate of lime and soda—will not serve in optics. In place of this, a double silicate of lead and potash must be used. The lead gives density to the glass, and consequently high refractive power. The crude materials must be as pure as practicable. To about a hundred parts of sand there is added a mixture of one hundred parts of minium, or red lead, and thirty parts of potash. When these are fused together in large, hooded crucible pots, a very liquid glass results. It is considerably more fusible than the lime-soda glass. So far, the process is easy; but the silicate of lead is so much heavier than the silicate of potash that when the fused mass is allowed to cool the denser silicate has a decided tendency to separate out at the bottom of the crucible. This makes the glass streaky and

quite unfit for use. To avoid this settling and secure a clear, homogeneous glass, that is the problem.

At the present time the best optical glass is probably made in France, and the methods there in use are consequently most worthy of examination. During the melting process the crucible is placed in the center of a domed furnace. The flames play around the crucible on all sides, making an intense heat possible. The hood prevents the furnace

gases from acting upon the compounds of lead and reducing them to the metallic state. The well-mixed batch is introduced in small quantities into the thoroughly heated crucible, and the charging process continued until the pot is completely filled. This will require from six to ten hours. The heat is then continued for perhaps four hours, at the end of which time the molten glass is vigorously stirred with a wrought-iron rod incased in a fire-clay cylinder.

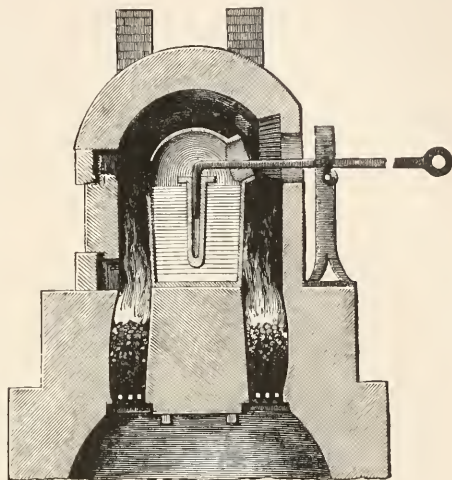


FIG. 1.—FLINT-GLASS FURNACE.

Then comes a second period of quiet heating and a second stirring. After this the stirrings succeed each other at every hour. When these hourly stirrings have been repeated perhaps half a dozen times, the crucible is allowed to cool down for a couple of hours. It is then heated to the utmost that the furnace will permit. As the result of this intermittent treatment, the glass is very liquid and is quite free from bubbles and striations. During the gradual cooling which succeeds this firing, a constant stirring is maintained for at least a couple of hours. When the stirring becomes too difficult, it is discontinued, and crucible and furnace are allowed to cool during a period of ten days or more.

The secret of making fine optical glass lies in this stirring. It was first carried out by Guinand, in Switzerland, in the early part of the century, and was introduced in Paris by Bon-temps.

When the cooling is accomplished, the crucible is removed from the furnace and broken, so as to free the mass of flint glass which it incloses. In spite of all this care, it must not be supposed that a mass of perfect glass is the result. On the contrary, it is full of flaws and imperfections, and only a part of it can be used. It is customary to grind and polish parallel faces on the

side of the mass, so that its defects may be located and the perfect portions utilized to the best advantage. The mass is cut into slabs suitable for working up into prisms, lenses, and other optical instruments.

When a large disk is to be made, such as the great lens of a refracting astronomical telescope, several attempts are frequently necessary before success is gained. Two or even three years may pass before suitable material is cast.

As the result of this very troublesome process, we have slabs of fairly homogeneous glass from 3·4 to 3·6 times as heavy as water. Although the greater density is about equal to that of the diamond, the refractive indices of the two substances are not the same. That of the diamond is 2·5 and of the flint glass 1·61. But even this refractive power is the key to many mysteries. The trouble of producing the material counts as nothing in face of the results.

The possibility of increasing the refractive index of optical glass by increasing the density early attracted the attention of experimenters. Since the beginning of the century attempts have been made in this direction. By the use of the heavier rare metals, such as thallium, a glass has been produced over five times as heavy as water. The material has served admirably for the manufacture of artificial jewels, but has not as yet found permanent application in science.

The refractive power of glass, by which the rays of light are bent out of their course and images of objects formed, has its disadvantages as well as its merits. It is almost impossible to construct a lens which shall converge the rays of light without, at the same time, producing rainbow colors around the image. This defect is called chromatic aberration, and, as one can readily see, is fatal to the definition of the lens. It is commonly overcome by employing a compound lens, made of flint and crown glass. The different refractive indices of the materials correct each other's aberration and produce white light. A lens so constructed is termed achromatic, since it does away with the fringe of color. Loss of power is naturally the price of such a correction. These difficulties led to the project of making lenses out of a material which should obviate the color fringe by something in the glass itself. It is found that titanate and boric acids have a marked effect upon the refraction of the differently colored rays, and compounds of these materials have been used to good purpose. We have here a field well worth further exploration.

The best flint glass for optical use is made in Europe. It is an interesting circumstance that the great establishments of Messrs. Chance and Company, at Birmingham, and M. Feil et Cie.—now M. Mantois—at Paris, which largely supply the Ameri-

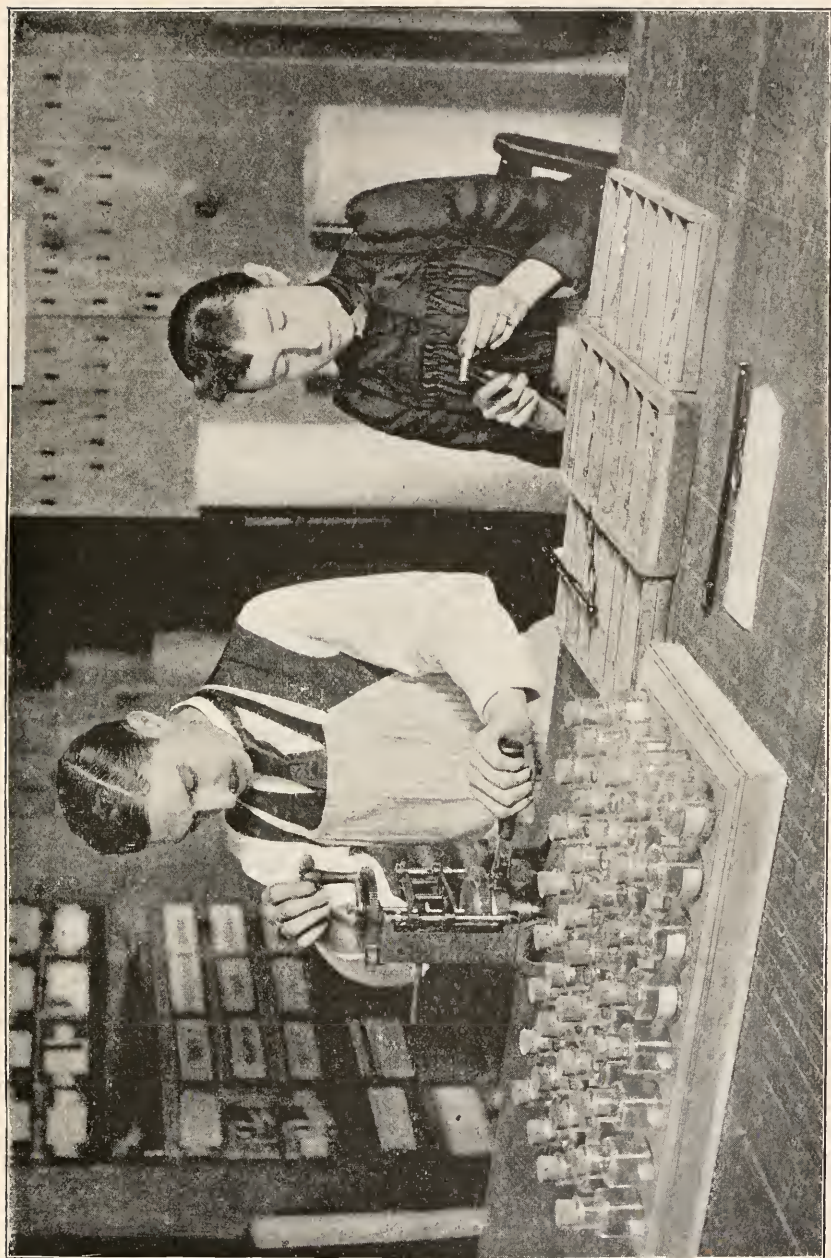


FIG. 2.—MAKING SPECTACLE-LENSES.

can market, are both, in this department at least, lineal descendants of the persevering Swiss watchmaker, Guinand, to whom we owe the present superiority of optical glass. The material is imported in convenient slabs for use in smaller articles and in rough disks for the larger lenses.

A noted French critic has left on record a touching account of the first time he ever looked through a pair of spectacles. He was terribly near-sighted, but no one had ever given sufficient attention to the defect to make any attempt to remedy it. One day, while still a boy, he got hold of his grandfather's spectacles, and put them on. Great was his surprise to find that the giant tree which shaded his play-ground was made up of individual and beautifully formed leaves instead of being, as he had previously supposed, one almost solid mass of green foliage. The boy fairly danced with delight, for a new world was suddenly opened to him.

A little fragment of glass, which thus gives sight to the almost blind, must claim attention even before the instrument which discloses either microcosm or macrocosm, for it has to do with the most important of all sciences, the science of daily living. The grinding of the small lenses for spectacles and eye-glasses is carried on in many establishments throughout the country and has been reduced to very accurate practice. Three surfaces are utilized—spherical curves, cylindrical curves, and prismatic faces. Their effect can readily be understood if one will consider for a moment the passage of a beam of light through an ordinary triangular prism. As the light is bent toward the common perpendicular on entering the glass, and away from the common perpendicular on leaving the glass, the total bending will be toward the base, or thicker portion. Now a lens may be considered a double prism; convex, if the two prisms be placed base to base, and concave if they be apex to apex. Since the light is always bent toward the thicker portion, the convex lenses converge the rays while the concave ones disperse them. In designing lenses for spectacles, these principles find application. If the eye be perfectly formed, but have too little or too great convexity, the remedy is found in glasses with simple spherical faces; but if the structure of the eye be faulty and non-symmetrical, as in the astigmatic, the glasses must have cylindrical or prismatic surfaces.

The bit of glass to be formed into a lens is fastened by means of pitch to a small block of hard rubber so that it may be more readily handled. It is ground by being pressed against a rapidly revolving metal tool, whose curvature is equal and opposite to that desired in the lens. This is known as the "rough tool" and is made of cast iron. It is mounted on a vertical spindle, and is kept moistened with emery and water. Several grades of emery are used in succession, changing from coarse to fine as the grinding proceeds. As a result of this process the glass has a rough surface and is no longer transparent. It is now transferred to the "fine tool." This is made of brass and has its surface as true

as possible. It is compared from time to time with a standard curve, in order to insure accuracy. In this second grinding the abrading material is rouge (carefully calcined sulphate of iron). Finally, the lens is polished by being pressed against a piece of cloth powdered with rouge and fastened to the rotating tool. The glass is now loosened from its block, turned over, and the reverse side of the lens ground. When this has been accomplished, the lens must be cut down to the proper shape for mounting in the spectacle-frame. It is placed on a leather cushion and held firmly in position by a rubber-tipped arm, while a diamond glass-cutter passing around an oval guide traces a similar oval on the glass below. The superfluous glass outside of the oval is removed by steel pincers, the rough edges are ground smooth on Scotch wheels, and the lens is ready for mounting. The glasses for small telescopes, microscopes, burning-glasses, and the like are ground in the same fashion.

When, however, it comes to grinding the lens for a large astronomical telescope, the process is slightly modified. The work is one requiring considerable skill and patience, though it involves no very great difficulties. It was formerly done entirely by hand and by individual workmen rather than by large firms. It will be remembered that the philosopher Spinoza earned his living by grinding lenses, and since his time less famous workmen have patiently pursued the same trade. At present the grinding of telescope lenses has assumed the proportions of a business, and has nowhere been carried to greater perfection than in America. The firm of Messrs. Alvan Clark and Sons, whose workshops are at Cambridgeport, Mass., have gained a reputation which extends on both sides of the Atlantic, as their lenses exceed in both quality and size even the best products of European skill. A great astronomical telescope is indeed quite cosmopolitan in its genesis. The glass is cast in Paris, the grinding is done in Massachusetts, the mountings are made in London or Berlin, and the telescope itself is pointed toward the heavens from Mount Hamilton or from the Russian Imperial Observatory at Pulkowa.

All the glass ground at Cambridgeport comes from the establishment of M. Mantois in Paris. It is imported in the shape of large disks, which are generally flat on both sides. The first grinding is done by machinery, the abrading material being Tilghman's chilled iron globules. These are found to be more effective than sand. The finer grinding is accomplished by means of varying grades of emery. It is in the finishing process that the American operations take rank over the foreign. The final touches and the polishing are all done by hand, the rouge being applied on the tip of the finger. It is necessary to employ constant tests during the course of the grinding. At first, these

are all mechanical and are made with a spherometer. Such tests, however, simply insure accurate curvature, and by their very nature can take no account of irregularities in the texture of the glass. These can only be detected and remedied by means of optical tests. When the preliminary polishing is finished, the lens

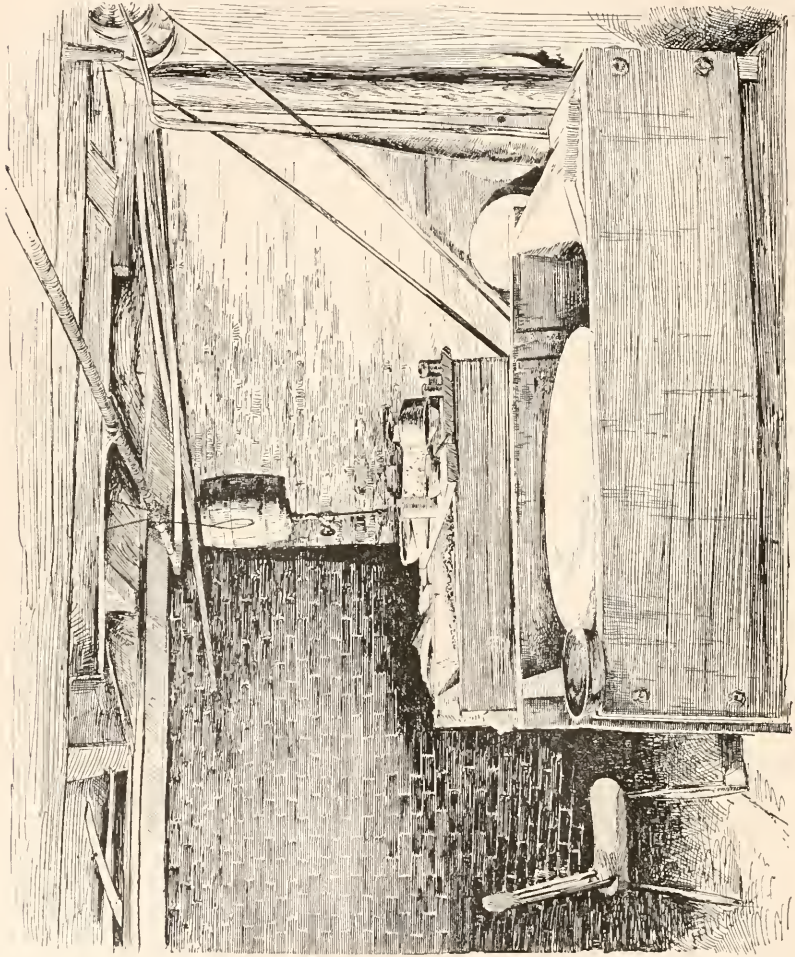


FIG. 3.—GRINDING TELESCOPE-LENSES.

is roughly mounted and submitted to a most rigid examination. A beam of light from what is called at the workshops an "artificial star" is transmitted through the lens and enables the workmen to locate defects of all sorts. The remedy is then a matter of touch and try, and, as one can readily imagine, is a long and tedious process. Still, the lens is not completed. It must now be submitted to the test of actual star-gazing. The most famous lens turned out by the Messrs. Clark, and indeed the largest in

existence, is the one now mounted in the Lick Observatory in California. It has an aperture of thirty-six inches in the clear. It was tested on seventy different nights, on veritable stars, before it was considered finished. It sometimes happens that important astronomical work is done with these temporarily mounted lenses, and some of them have quite a history. Thus, in *ante-bellum* days, an eighteen-inch objective was ground for the University of Mississippi, but, the war coming on, the lens was never sent for. It was afterward used at Chicago, and is now doing good work at Evanston, Ill. While it was temporarily mounted at Cambridgeport, Mr. Alvan G. Clark discovered the companion to the dog-star Sirius, a discovery for which he was awarded the Laland prize by the Imperial Academy of Paris. At the present time a twenty-inch objective for the University of Denver is in progress, while a forty-inch disk of crown glass awaits transformation into a lens for the University of Southern California. It was at first feared that such giant lenses would suffer injury by warping, but the experience at Mount Hamilton has been so reassuring that the present tendency is toward even larger glasses.

It would still be a difficult task, though a less difficult one than the present, if it were simply required to produce a perfect curvature, but the superiority of a lens depends upon its chemical composition as well as upon its geometric form. The problem may be summed up by stating that one must have as homogeneous a material as possible, to start with, and as symmetrical a form as the inequalities in the material will permit, to end with, the theoretical curves being in practice slightly modified to obviate any small irregularities in density.

The crown-glass lens with which the flint glass is combined in order to obtain achromatism is made in the same way, only that the material is a lime-soda silicate similar to that used in window glass instead of having lead and potash as its bases.

It would be easy to multiply illustrations of the use which science makes of the refractive power of glass, as in the stereopticon, the kaleidoscope, the camera, the projecting lantern, and in other apparatus of scientific or popular nature; but in the manufacture of all of them these two principles hold—the production of a heavy, uniform glass, and the shaping of this material into suitable form by processes of grinding and polishing.

There is, however, one application so important to philosophic thinking as to deserve special mention, even though it involves no new principle. What the astronomical telescope has been in the study of the physical features of the heavenly bodies, the glass prism is in the investigation of their chemical constitution. Had one spoken but a few years ago about the chemistry of the sun and stars, and seriously proposed their analysis, his hearers

would probably have tapped their foreheads significantly and perhaps even winked at one another. But to-day stellar chemistry is a recognized branch of cosmical research. If a ray of sunlight be passed through a glass prism, it gives a bright, continuous spectrum, varying in color from red to violet. If the source of light be a vapor of a metal, or metallic salt, the continuous spectrum is replaced by one or several bright lines whose position and color are invariable for the same metal. If a more intense white light be allowed to pass through the metallic vapor, the former bright lines appear black, but are easily recognized by their number and position. In the solar spectrum a whole series of such black lines are distinguishable, and by correspondence they are believed to indicate the presence of at least seventeen of our earth elements, while there appears to be at least one element in the solar atmosphere for which we have no counterpart on earth. A similar study of the light of the stars has disclosed in their atmosphere a number of earth elements and has indicated the presence of others unknown on earth. This little piece of flint glass, ground into the shape of a triangular prism, has proved the "open sesame" to secrets so profound that in its absence they must have been regarded as belonging to the great domain of the unknowable. It is something of a triumph for the near-sighted philosopher on our planet to announce that he has discovered magnesium on the star Aldebaran and sodium on Sirius.

While the refractive power of glass opens so many wonderful possibilities, its simple transparency is a quality which adapts it for many less ambitious uses. Much of the work of science is that of measurement. Sir William Thomson has indeed said that in any branch of research we have only so much science as we have mathematics. For this service of measurement, glass is admirably adapted. The measurement of heat by the thermometer is an example of a frequent and important operation, while the manufacture of the instrument itself is a type of many similar processes.

The ordinary thermometer measures heat by the expansion of some such liquid as mercury. The increase in bulk for any slight increment of heat would be too small, however, to be perceptible in a mass of the fluid metal. Hence the necessity for the glass-blower's skill by which the increased volume is made sensible to the eye. By having a comparatively large bulb in connection with a tube of very fine bore, the slightest expansion in the volume of the mercury becomes at once apparent by a relatively large change of level of the fluid in the tube. The greater the discrepancy between the bulb and the tube, the more sensitive the instrument.

The operation of making a thermometer begins in the crucible-

pot. The glass-blower dips his blowpipe into the molten mass of glass, withdrawing a small quantity of the material with his pipe. The plastic mass is rolled into a pear-shaped ball on the marvering table. A little air is then blown into the center of the

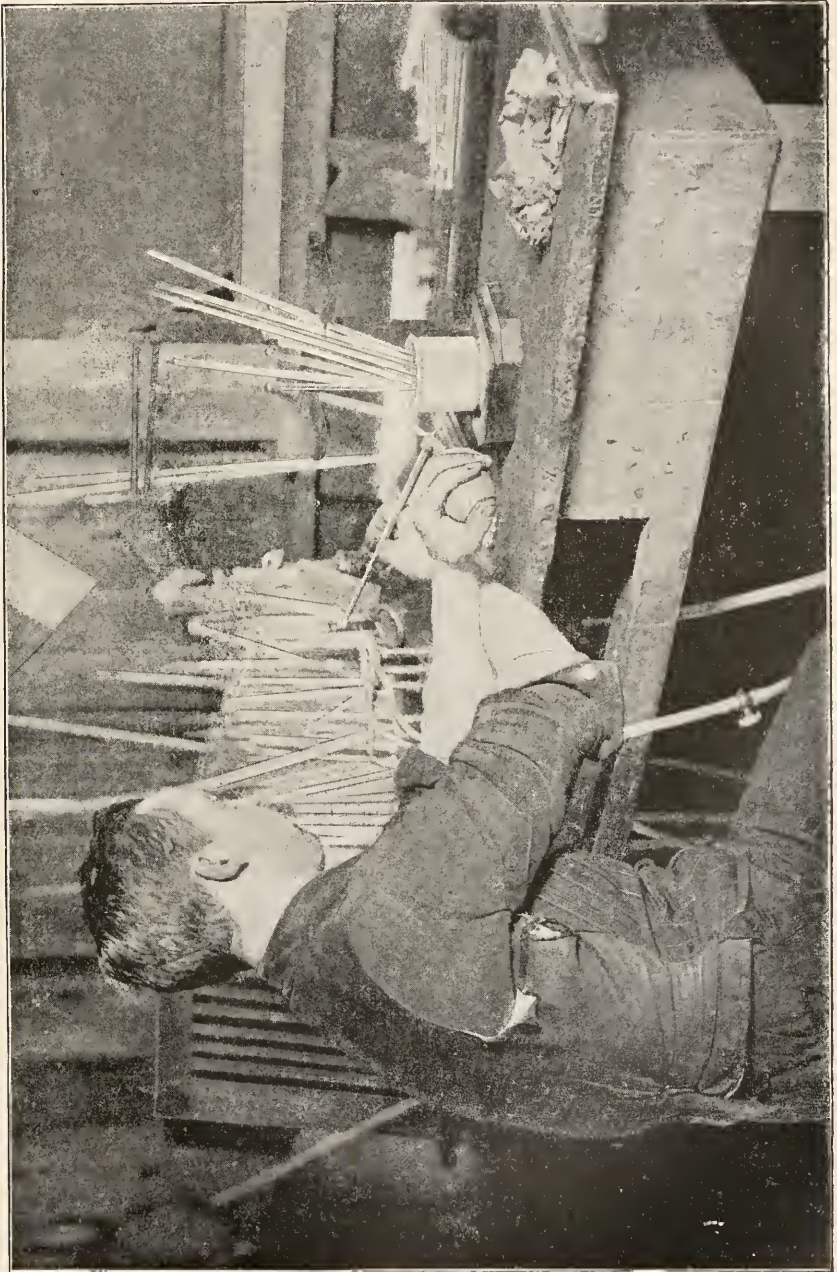


FIG. 4.—BLOWING THERMOMETER-BULBS.

mass, and a second workman attaches the end of his iron rod or "punky" to the free end of the ball. The blower remains stationary, while the second man walks away from him, carrying his punky with him. In this way the mass of glass is drawn into a long tube, perhaps fifty feet long, the bubble of air preserving a fine opening throughout the entire length of the tube. In the better thermometers, the tube is somewhat flattened, so as to make the thread of mercury more visible, and a background of opaque white glass is added for the same purpose. These modifications are made more easily, perhaps, than one would imagine. By flattening the ball of glass before it is drawn into a tube, the elliptical cross-section is secured, while a string of opaque glass welded on to the still plastic ball becomes elongated into a thin plating on one side of the tube.

It is impossible in this way to secure tubes of absolutely uniform bore, but the inequalities are much less than one would suppose. For ordinary instruments the variation may be neglected. The tubes are then cut into convenient length and sent to the workshop of the thermometer-maker. One can readily pass a whole morning in the little room where he works, for there is a certain interest attaching to so individual a task as this which is not found in more wholesale production. The instrument-maker sits on a high stool before his work-table, his principal tool being a conveniently arranged blowpipe. This is not the hand and mouth tool used by mineralogists and jewelers, but is a permanent blowpipe fed by gas and operated by a blast of air.

The first operation is that of forming the bulb. In the better instruments this is made out of a separate piece of glass and is then attached to the tube. In this case the bulb is made cylindrical in form, so as to afford large capacity without too great diameter. In the less expensive thermometers, the bulb is formed directly on the end of the tube itself. The glass is first fused in the blowpipe flame until the end is entirely sealed. A short rubber hose with a small rubber ball on the opposite end is then slipped over the open end of the thermometer-tube. The sealed end of the tube is again softened before the blowpipe, and then, by simply pressing the rubber ball, the air forces the plastic glass into a symmetrical bulb. It is a pretty little operation, for the glass responds so delicately to the thought of the workman.

It is found that glass undergoes a slow contraction during a period of two or three years, and, where great accuracy is desired, the tube must be put away for that time to season.

The bulb and tube are now to be filled with mercury. The tube is much too fine to allow the mercury simply to be poured into the bulb. Indirect means must be used. The open end of the tube is softened and quickly blown into a large bulb, while

the end is drawn into a fine jet. This is hastily plunged beneath the surface of a bath of pure mercury while the whole thermometer is still hot. As it cools, the air inside shrinks and the mercury

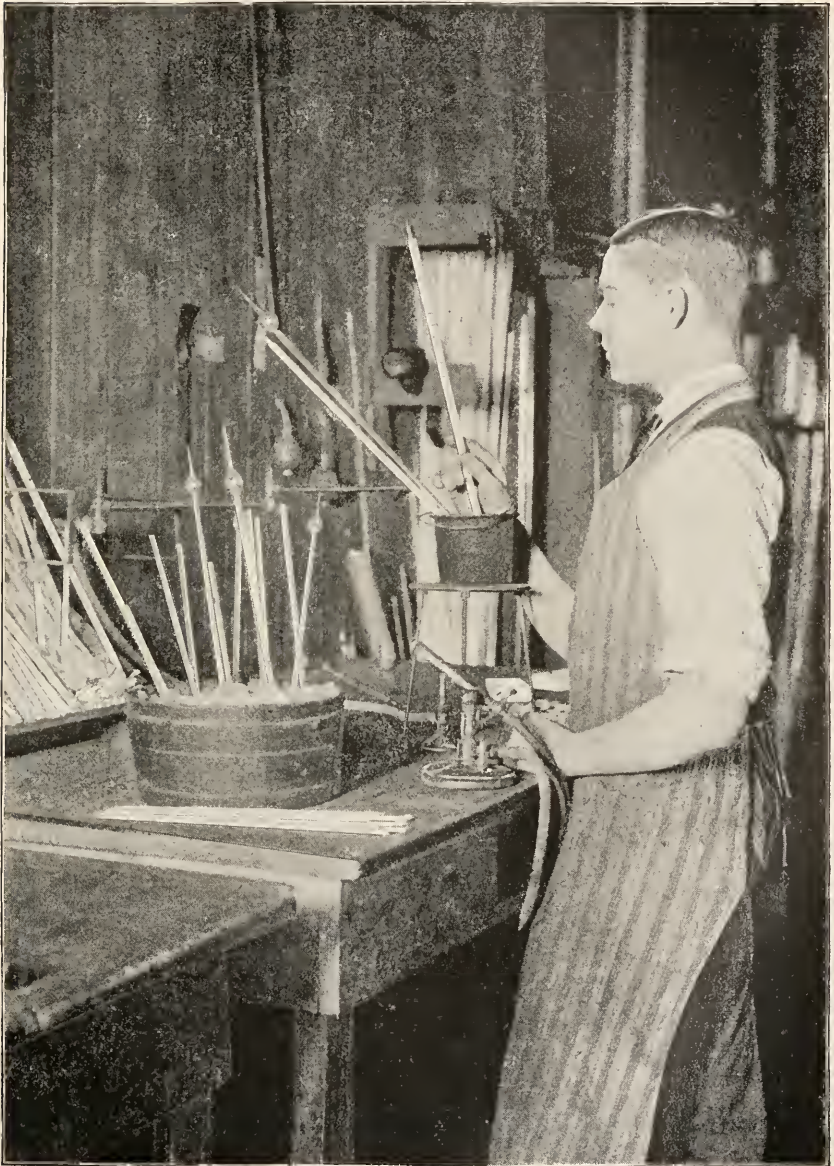


FIG. 5.—CALIBRATING THERMOMETERS.

rises into the outer bulb. The permanent bulb is then carefully warmed, the tube being in a horizontal position so that the expanding air may freely escape. The tube is then held vertically

and allowed to cool. The mercury in this position closes the upper end of the tube, and as the cooling proceeds it is sucked through the capillary opening and falls, drop by drop, into the bulb below. The process is repeated, if necessary, until the lower bulb is filled with mercury. The thermometer is then heated. The mercury expands, driving out all the air and filling both bulb and tube. The temporary bulb is now removed, and the open end of the tube is closed before the blowpipe. The thermometer is ready for calibration.

The bulb is buried in cracked ice, from which the water is allowed free drainage. When the mercury no longer contracts, a mark is made on the tube at a level with the mercury. This is the freezing-point of water, 0° on the centigrade scale, or 32° on the Fahrenheit. Réaumur's scale, with the freezing-point at 0° and the boiling-point at 80° , although so extensively used in Germany and Russia, is seldom seen in this country. The thermometer is then transferred to a bath of boiling water. The mercury quickly rises, and soon again becomes stationary. The tube is marked for the second time. This is the boiling-point of water, 100° centigrade, or 212° Fahrenheit. As the temperature of the boiling-point varies with the atmospheric pressure, the barometer must be read and a corresponding correction made, or else a standard thermometer must be kept in the bath, and the marking made in harmony with that. These two points determined, the operation of making a thermometer is almost completed. It has now only to be marked.

The tube is dipped into a bath of melted beeswax, and as soon as the thin layer of wax hardens it is taken to the dividing-engine. The space between the freezing and boiling points is here divided off into 100 divisions if the centigrade scale is to be employed, or into 180 divisions if the Fahrenheit be used. Every tenth line is made somewhat longer than the others, and is the only one marked. The marking is done on a machine constructed after the order of a pantograph. The waxed tube is laid on a small sliding platform and secured to its bed by a few drops of melted wax. A sharp stylus is then brought to bear upon the point where the marking is first wanted. The movement of the stylus is controlled by a long lever, whose own movement is, in turn, controlled by the action of a second stylus. This is made to pass over the desired figures cut in brass on a lower platform of the machine. The action of the system of levers is to reduce the motion of the upper stylus, and consequently the size of the figures traced through the wax. In this way accurate marking is secured on a sufficiently small scale. The tube, thus lined and marked, must now be subjected to the action of hydrofluoric acid. A solution of the acid in water, to which some alkaline salt has

been added, is rubbed over the tube. In a few moments the glass is sufficiently bitten. The tube is washed with water and the wax removed. The lines and figures are then blackened with varnish, and the thermometer is ready for use.

It must not be supposed that the same care is employed in the



FIG. 6.—THE DIVIDING-ENGINE.

construction of the ordinary instruments sold in the shops for domestic usage. Their low price would preclude that. They are made in large quantities, and their calibration is only approximate. They have been known to be as much as six or eight degrees out of the way; but that is much worse than the average. After one has watched the construction of a scientific thermometer, he wonders not that they should cost a couple of dollars or more, but rather that they can be sold at such a price.

For many purposes, such as the systematic observation of the weather, it is desirable to have thermometers which shall register the highest and lowest temperature reached. These maximum and minimum instruments require additional care on the part of the thermometer-maker. In the latest pattern manufactured for the Signal Service a decided improvement has been made in the self-registering device for maximum temperatures. The bore of the tube is greatly contracted at a point somewhat below the lowest reading that will probably be required, and the thermometer is usually placed in a horizontal position. Under the action of an increasing temperature, the mercury expands and forces itself through the very narrow opening. But when the temperature falls, the mercury will not pass through this opening, and all the shrinkage of the fluid in the bulb takes place below the contraction. As a consequence, the column of mercury remains stationary, and so records the highest temperature reached. By vigorous shaking the instrument is readily reset.

In the thermometer for registering the lowest temperature colored alcohol replaces mercury. A little rider of glass is so trimmed with fine hairs at each end that, while it does not fit in the tube with sufficient snugness to prevent its being pushed down the tube by the retreating meniscus at the surface of the alcohol, it will become wedged in place when the column ascends.

The special feature to be noticed in the manufacture of the thermometer is the individuality of the process. Each instrument is the subject of a separate operation. The same principle is applied in the manufacture of barometers and hydrometers. In the fabrication of the first, a glass tube is simply closed at one end and then filled with pure mercury, from which all the air has been expelled by boiling. Its subsequent marking and adjustment in a suitable frame are only matters of careful handling.

In the fabrication of hydrometers more special work comes in. The transparency of the material is not here an essential feature, although it is utilized and the graduation placed inside of the tube. The quality which renders glass particularly available for this service is its indifference to chemical reagents and its constant weight. The principle upon which hydrometers are constructed is familiar to all. In order that an object may float,

it must displace its own weight of the supporting fluid. If, then, a float of invariable weight be immersed in a liquid, the depth to which it sinks will be a measure of the specific gravity of the

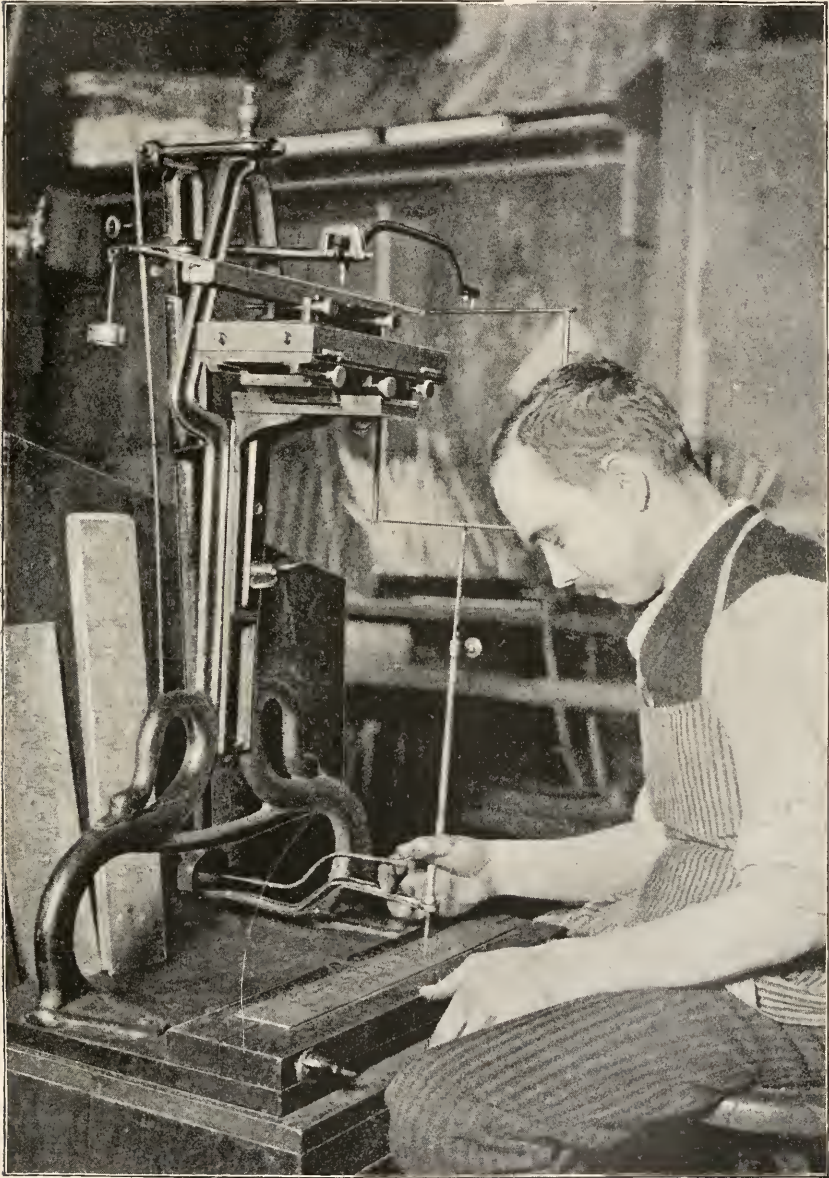


FIG. 7.—MARKING THERMOMETERS.

liquid. The hydrometer is simply such a float as this. It is made in different forms and styles, according to the use for which it is intended; but in all cases it is essentially a cylinder or bulb of

glass, loaded at the bottom with either mercury or shot, and terminating above in a slender, graduated tube. The weight of the metal so lowers the center of gravity that the instrument always floats in a vertical position. A suitable length of plain

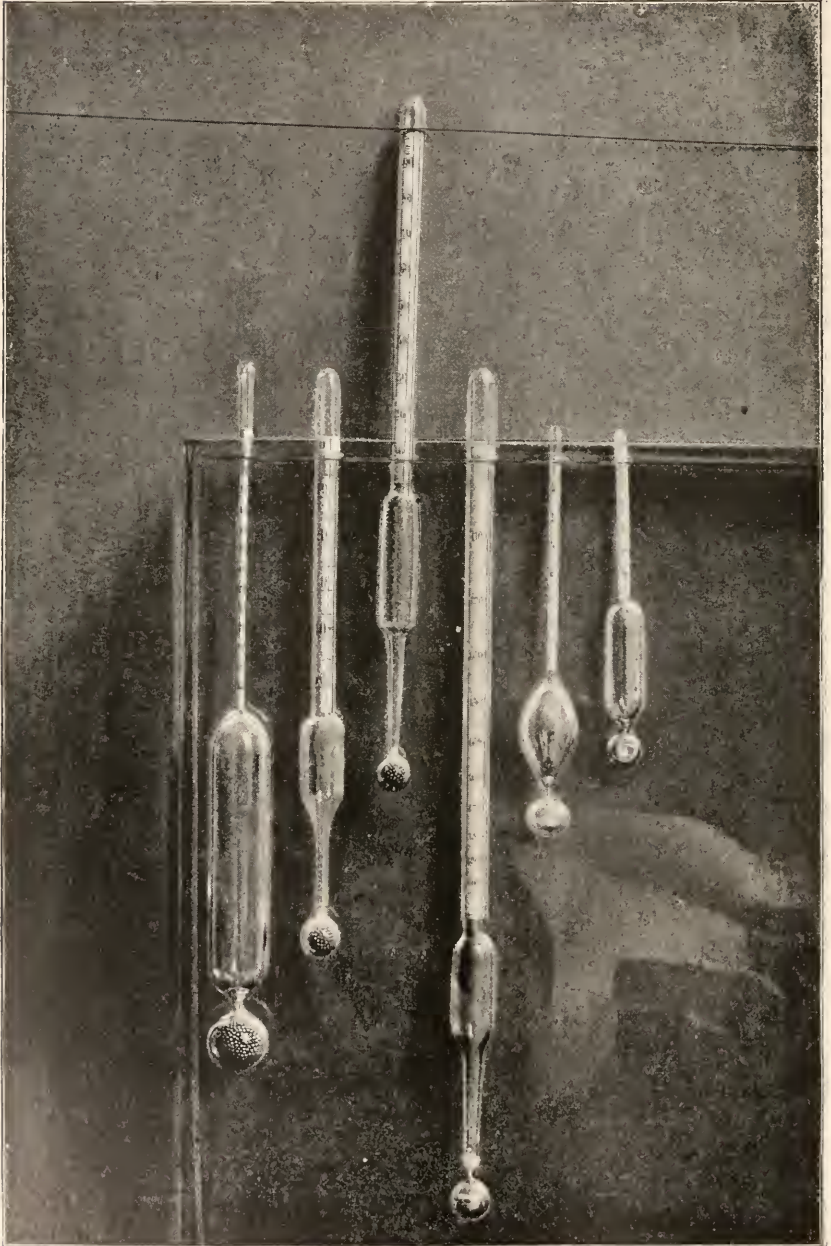


FIG. 8.—VARIOUS FORMS OF HYDROMETERS.

glass tubing is taken by the glass-blower and sealed at one end. A bulb is then formed for the reception of the ballast, and the upper end is drawn out into a smaller tube. Mercury or shot is then added until the instrument floats in an upright position. It is placed in pure distilled water at 60° Fahrenheit. If the hydrometer is to be used for measuring the specific gravity of liquids heavier than water, it is loaded until the level of the water almost reaches the top of the tube. The instrument is then placed in a second heavier liquid of known specific gravity. It will come to rest farther out of the fluid than before, since it must needs displace less in order to float. This second point established, it is easy to construct the scale. If the hydrometer is to be used for liquids lighter than water, let us say for alcohol, it is so loaded that when placed in pure water the level will only reach up to the lower part of the tube. It is then placed in a lighter liquid of known specific gravity. It will sink lower in this case, since it must needs displace more of the fluid in order to float. This second point established, it is an easy matter to continue the graduation upward in space and downward numerically. The scale employed depends upon circumstances. In the direct-reading hydrometers, the point to which the instrument sinks in pure water is marked one, and the other readings express directly the specific gravity of the fluid into which it is plunged. In others, the scale is empirical—that is to say, the degrees bear no relation to actual specific gravities. In certain manufacturing processes such scales are used with the purpose of keeping trade secrets. Where the hydrometer is for a special use, such as measuring the specific gravity of alcohol, it is known as an alcoholometer, and the marking ascends from pure water at the bottom of the graduated tube to pure alcohol at the top. The degrees give at once the percentage of alcohol in the liquid under examination. One of the most familiar special forms is the lactometer, the hydrometer used for measuring the specific gravity of milk. The scale is commonly drawn on a piece of paper which is fastened inside the tube in the right position. The end is then sealed before the blowpipe, and the instrument is ready for use.

The manufacture of pressure-gauges and other glass instruments for measurement proceeds in much the same fashion.

In chemical and physical laboratories the use of glass instruments is a simple necessity. Combustion-tubes, beakers, funnels, test-tubes, watch-crystals, burettes, pipettes, absorption bulbs, bell-jars, flasks, apparatus for electrolytic decompositions, and a hundred other essential articles could scarcely be made of any other material. Here the transparency of the glass, its great strength, and its almost total indifference to the action of reagents give it special suitability. The principles involved in the manufact-

ure of these objects are simply ingenious modifications of those involved in processes already described. Most of the scientific apparatus in glass is brought from Thuringia. Our own workmen do not seem to have that turn for science which is shown by the Germans. Even the little apparatus which is made in this country is for the most part the work of foreign artisans.

It would be a grave omission to close even so brief a summary of the office served by glass in science without calling attention in a few words to one of the latest and most interesting lines of research which it has made possible. We refer, of course, to the vacuum tubes employed by Mr. Crookes in his well-known investigations into the properties of radiant matter. We have been ac-

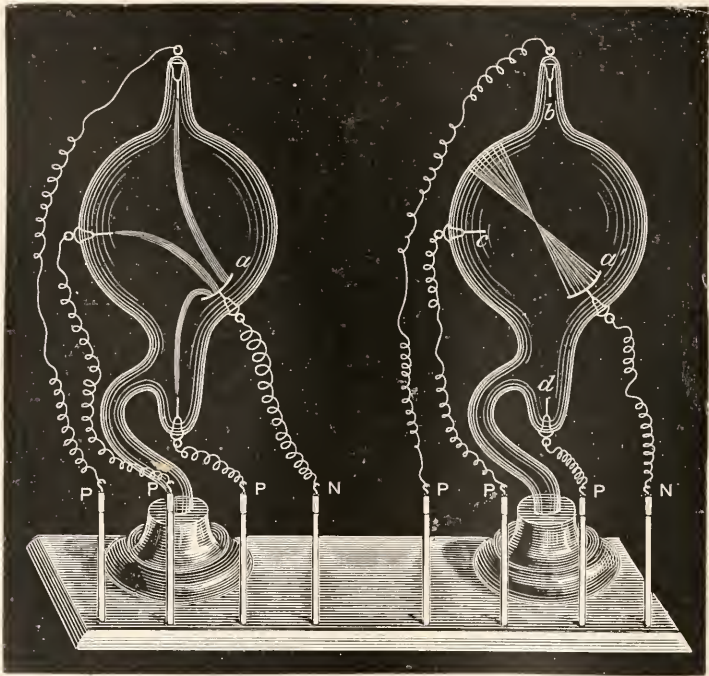


FIG. 9.—VACUUM TUBES.

customed to talk somewhat glibly about the three states of matter. To this list we are now asked to add a fourth, the radiant. Faraday's hint and the work of Mr. Crookes have well-nigh established the distinction between gas and radiant matter. In a gas under ordinary tension the molecules are in sufficient number to suffer almost constant collision with one another; but if the tension be low enough, say the one five-millionth of an atmosphere, the collisions become infrequent, and the molecules travel in almost uninterrupted straight lines until they come into con-

tact with the sides of the containing vessel. For this state of matter the term *radiant* seems at once appropriate and happy, for matter so attenuated exhibits phenomena apparently entitling it to a separate class and name. The radiant-matter tubes are simply bulbs or cylinders of glass several inches long and perhaps three or four inches in diameter, which contain only the most minute traces of gaseous matter. Metallic terminals for electric connection are sealed into the glass. These are given various shapes and positions, so that the behavior of radiant matter under different conditions may be observed. The manufacture of radiant-matter tubes is a work of dexterous glass-blowing. In the simpler forms a plain cylindrical tube is taken as the basis, and is sealed at one end. After the electrodes have been put in place, the other end is drawn into a fine tube, which is also sealed as soon as the exhaustion has been accomplished. Some of these tubes have been made experimentally in this country and more in England, but the home of this industry is also to be found in the Thüringer Wald. They deserve special mention in this connection, since no other material than glass would serve for such investigations.

The philosopher was formerly represented as a seated figure in a gown, and surrounded by hour-glass and old folios. To-day he is more active. He is better pictured in a blouse, and standing, surrounded with the apparatus of science. In his search for power he has brought new material to his service, and none of greater value than that which enables him to study distant globes, to investigate the inner history of an infinitesimal world, to find out the chemistry of the stars, and to pry into the properties and constitution of matter. But he stands there not in pride. The figure is one which breathes a deep humility. Each victory over the unknown only makes him the more sensible of the infinite world beyond his present vision. The office of science is corrective and disciplinary. It teaches one of its deepest lessons when it opens the eyes to the recognition of that which is unseen. The evolution of true power is the evolution of a spiritual insight which, in perceiving the known, perceives also the existence of something beyond. The greatest service of glass lies not in the definite knowledge which it brings us, but rather in the stimulating possibilities which this knowledge suggests.

THE result of Mr. Horatio Hale's examination of the subject, communicated by him to the International Congress of Americanists, is that "so far as our present knowledge extends, the theory that would trace the origin of the population of America, or any portion of it, to the Polynesian race, finds no countenance in the testimony of language, and is made extremely improbable by the very recent appearance of that race in the eastern Pacific islands."

ESTABLISHED BY EDWARD L. YOUMANS.

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THE DOCTRINE OF EVOLUTION: ITS SCOPE AND
INFLUENCE.*

By JOHN FISKE.

IF you take up almost any manual or compendium of history written before the middle of the present century, you will generally find it to be a lifeless catalogue of events, and more likely than not an indiscriminating catalogue in which important and trivial events are jumbled together in utter obliviousness of any such thing as historical perspective. Of great and admirable books of history there were indeed many by illustrious writers of ancient and modern times, in which the men, the measures, and the social features of particular epochs were portrayed with life-like reality and often illustrated and criticised with a wealth of practical wisdom. But the insight into the underlying causes and the general drift of the endlessly complicated mass of human affairs was dim and uncertain, and of the essential unity of history, the solidarity in the multifarious career of mankind, there was hardly a suspicion. Three great books in narrative form, which reached out toward a presentation of the unity of history, may be cited in illustration of the difficulty under which all such attempts necessarily labored in the absence of such broad scientific conceptions as have been gained only within recent times. Bossuet's Discourse on Universal History was a work of noble design; but, being necessarily limited by the narrow theology of the time, it could only see the vast importance of the work of the Hebrew race, and, seeing no further, could not properly estimate even this; while as for any appreciation of natural causes, its perpetual appeal to the miraculous made anything of the sort quite impossible. In Voltaire's Essay on the Manners and Morals of Nations there

* Address before the Brooklyn Ethical Association, May 31, 1891.